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(54) Abstract Title
Subsea Wellhead Assembly with Annulus Circulation Flowpath

(57) A wellhead system includes a tubing spool (180, fig 2B), adapted for mounting on a subsea wellhead (12, fig 2B), and a tree assembly 190 connected to the top of the tubing spool. The tubing spool and tree assembly include a concentric production flowbore P extending therethrough. An annulus circulation flow path A extends from the lower end of the tubing spool, around the tubing hanger (30, fig 2B), to a second annular space 120 and around the production and swab valves 100, 102 in the valve tree 190. A crossover port 90 may also be provided to connect the annulus flowpath A with the production flowpath P within the valve tree 190. The annulus circulation flowpath may be completely within the walls of the tubing spool and the valve tree. In use, the annulus flowpath A may be connected to the surface by a flexible conduit 250.

Fig. 2A

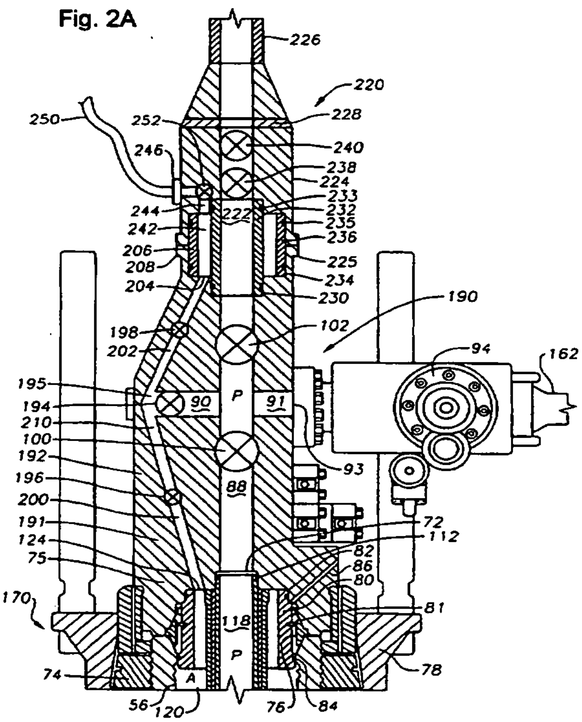

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Fig. 1A

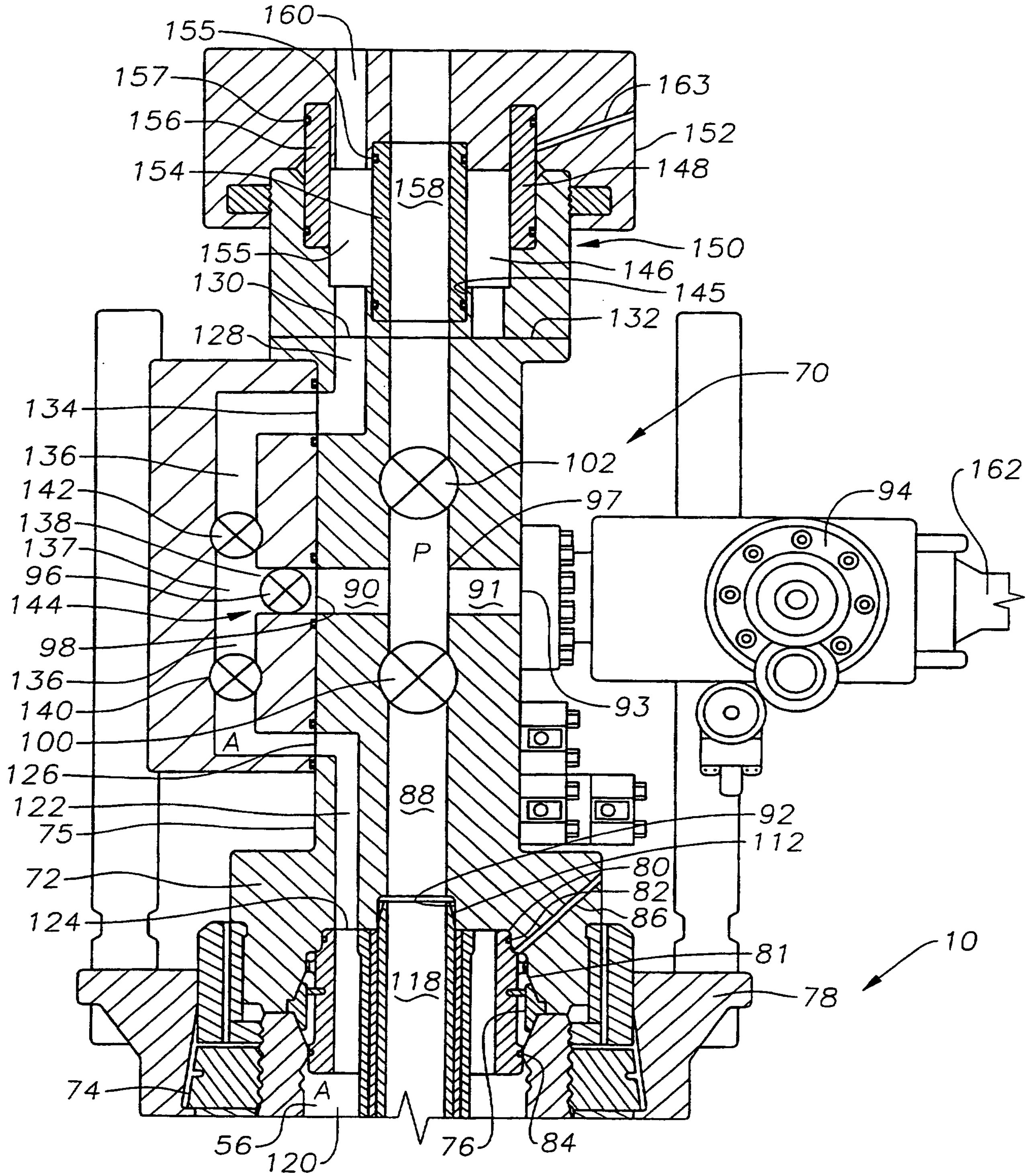

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Fig. 1B

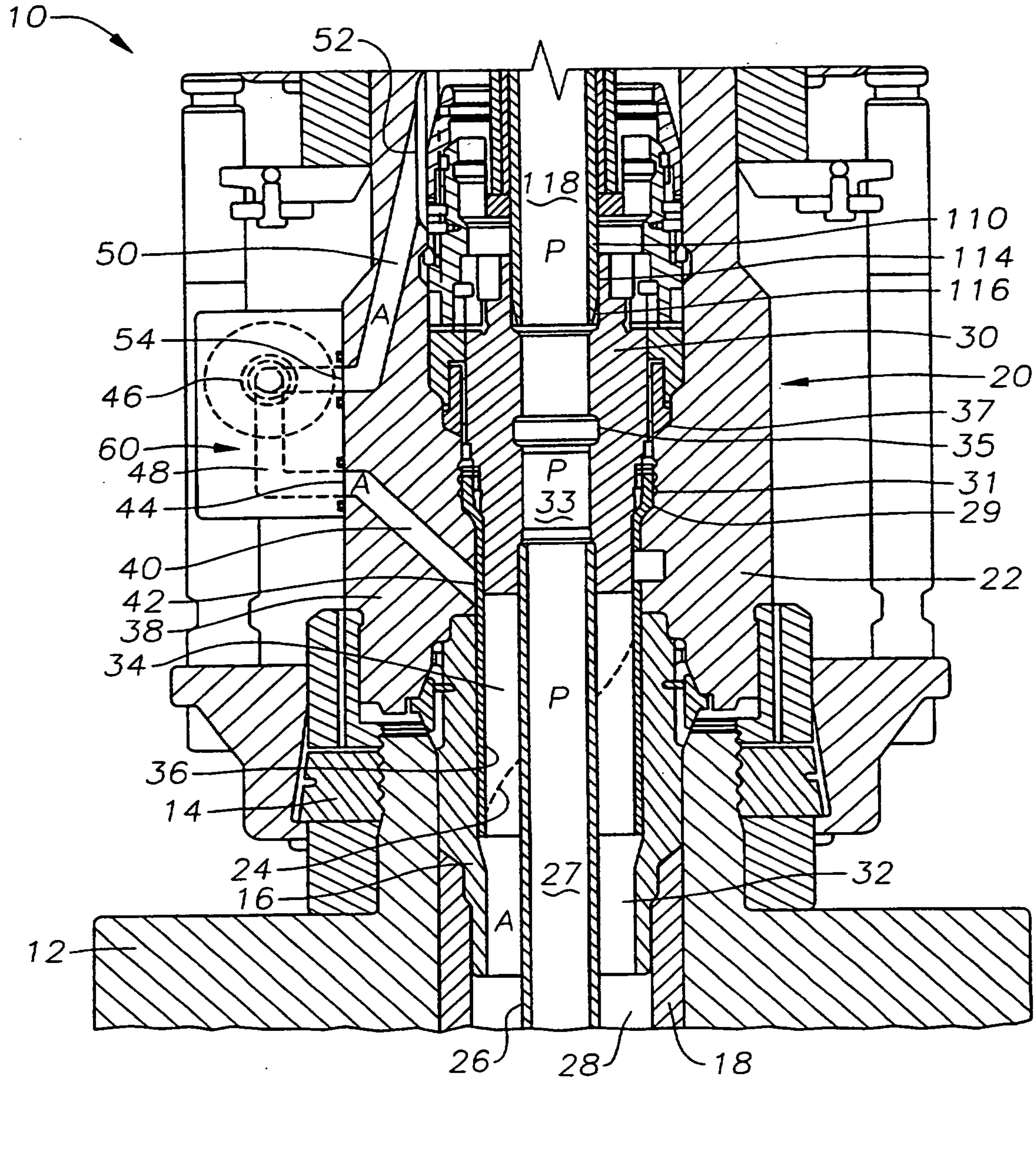
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Fig. 2A

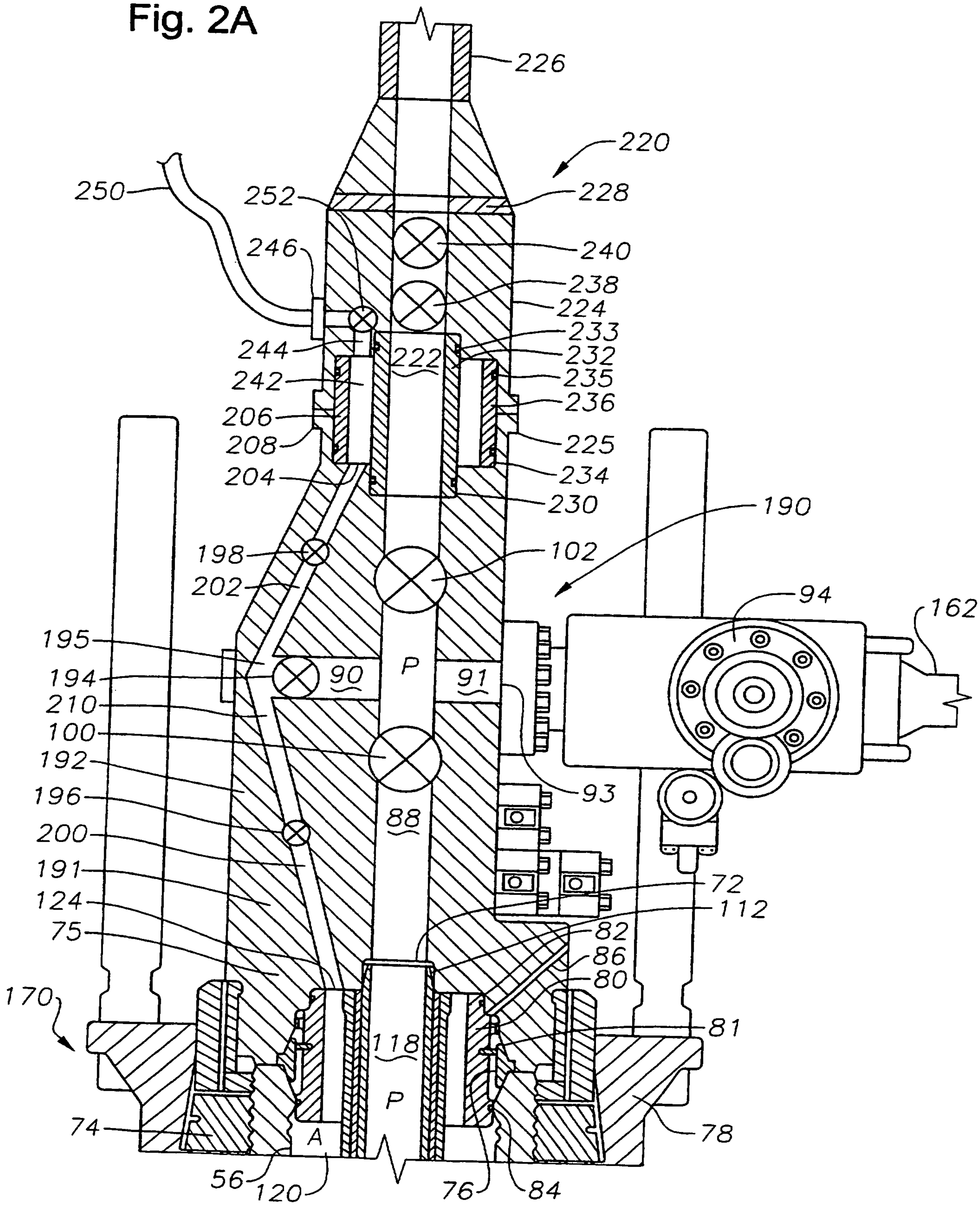

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Fig. 2B

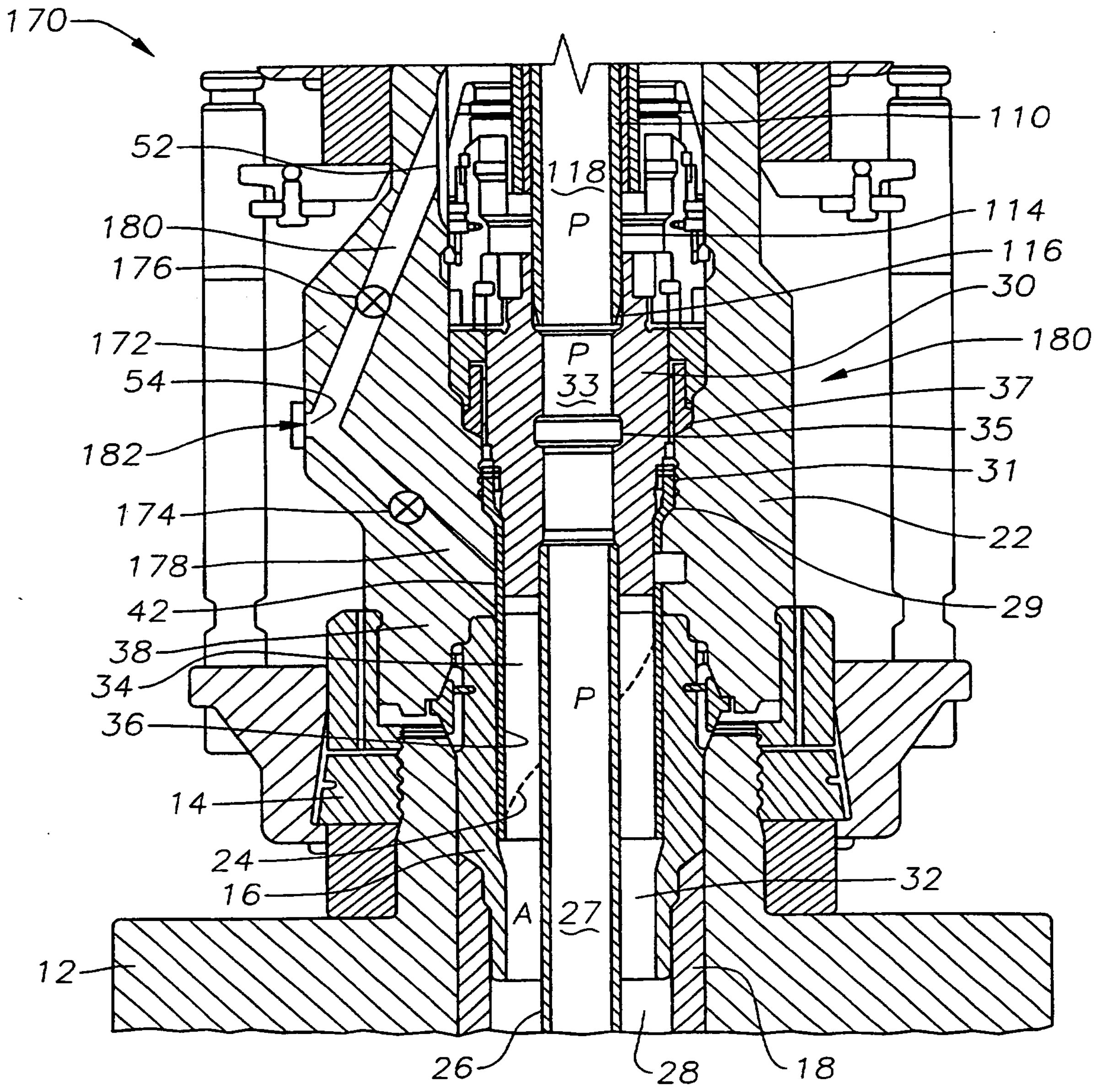
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Fig. 3

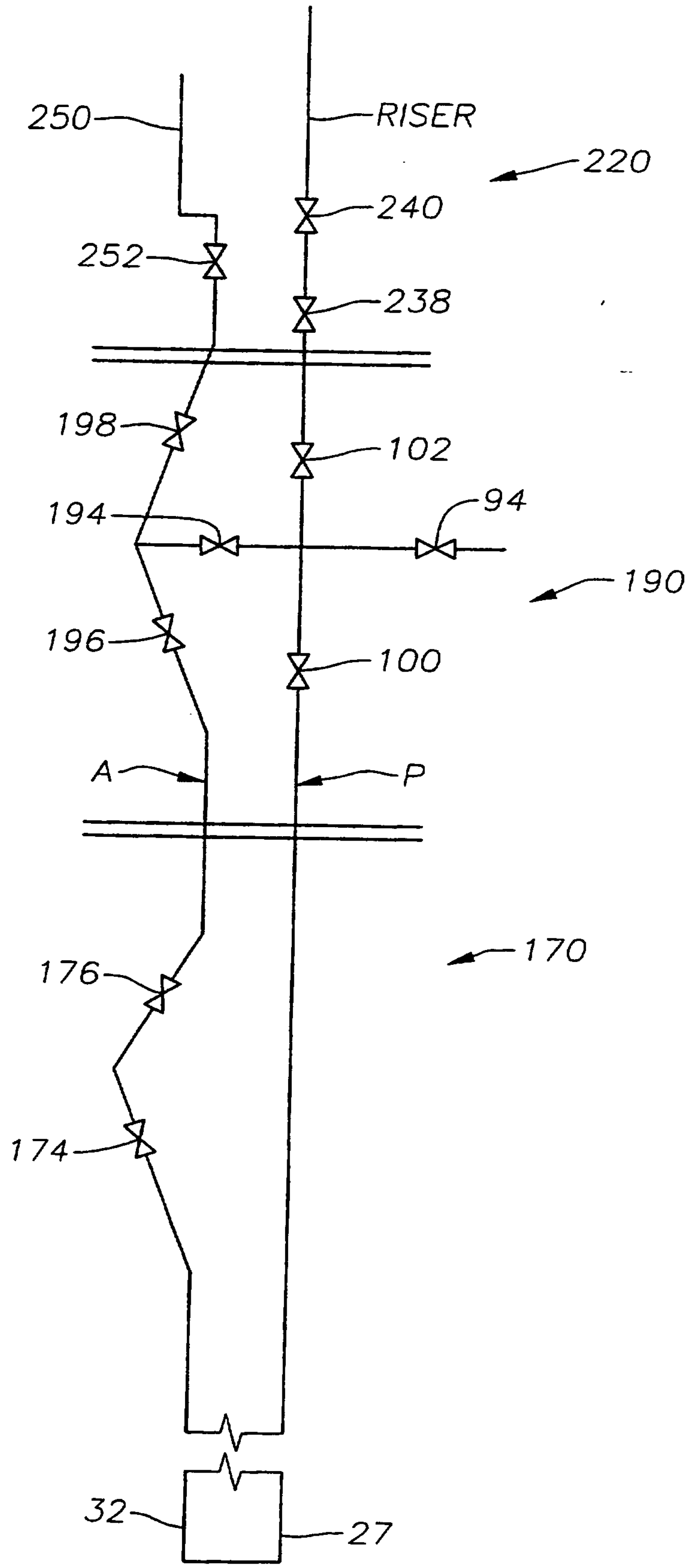
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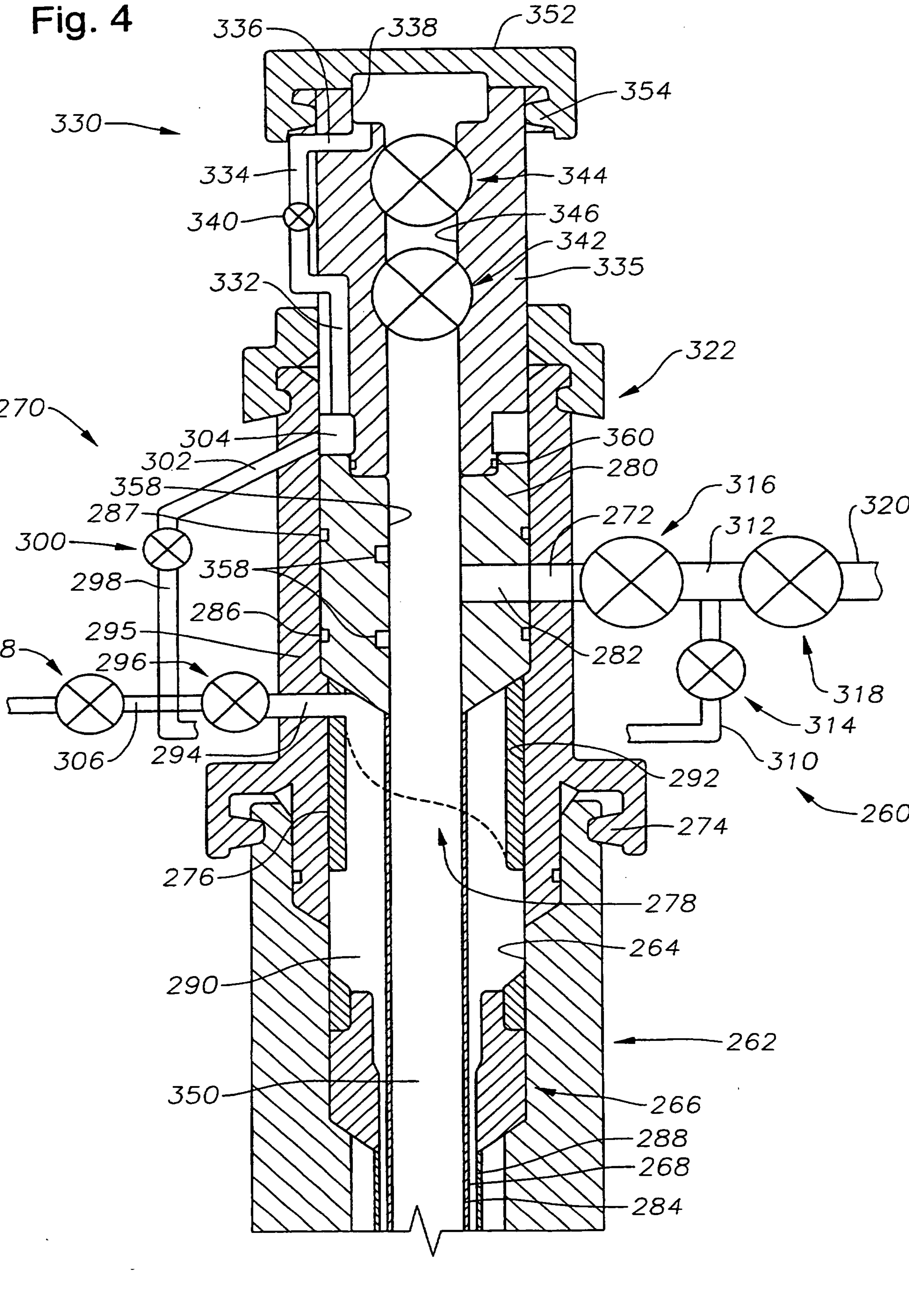
Fig. 4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WELLHEAD ASSEMBLY

The present invention relates generally to wellhead systems and more particularly, to wellhead systems for annulus circulation and still more particularly to a wellhead system having a concentric production bore and an annulus passageway extending through a tubing spool and tree assembly in the wellhead system.

Early designs for subsea wells mounted the x'mas tree on the platform. The tree included a tubing spool which supported a tubing hanger suspending production tubing through a drilling riser that extended from the surface and into the wellbore at the subsea floor. The production bore through the tree, tubing hanger and tubing was concentric to the wellbore. A side outlet was provided through the side of the tubing spool and below the tubing hanger to obtain access to the annulus formed between the production tubing and riser. An annulus access valve mounted on the tubing spool controlled flow through the side outlet.

With increased water depths, the tree was disposed subsea and access to the production tubing annulus below the tubing hanger was achieved by a diver connecting a conduit to the side outlet valve on the tubing spool and the conduit extending to the surface. To eliminate this conduit, a series of apparatus and methods were designed to communicate with the production tubing annulus through a port that passed through the tubing hanger itself. The ported tubing hanger allowed annulus pressure access from below the tubing hanger through the tree and then through the riser or flowline. The port extended through the tubing hanger to one side of the concentric production bore which passed through the center of the tubing hanger. The ported tubing hanger allowed the annulus fluid path to be directly connected to the tree piping for ease of monitoring, venting, circulation, crossover, and gas lift.

The disadvantage to ported tubing hanger was that a valve or other pressure retaining device had to be installed in the port through the tubing hanger to close the production tubing annulus when the tree was removed. Plugs were placed in the access bore to the valves. Various types of valve designs were also utilized, such as poppet-type back pressure valves and hydraulically shifted spool-type valves. Due to the limited tubing hanger diameter available, frequently more than one of these ports with valves had to be used to gain the required annulus flow area through the tubing hanger. Such valves are generally considered a liability from the standpoint of reliability of sealing and actuation, the ability to test, and to achieve an indication of their position. Gate valves with actuators and overrides are the preferred flow control device for wells, but cannot be used within the body of the tubing hanger. Further, these ports and associated valves utilized space around the production bore and thus restricted the size of the production bore for a given size tubing hanger.

As wells were completed at even greater depths subsea, it became difficult for divers to hook up a conduit to the annulus access valve. One method of obtaining annulus access was through poppet valves disposed in the ports through the tubing hanger. When the tree landed, spring-biased pins were depressed to open the poppet valves for access to the annulus. This allowed the fluid in the annulus to flow through the tubing hanger. No plugs were required to close the access to the poppet valves. Once the tree was removed, springs closed the poppet valves. Another advantage in allowing annulus flow through the tubing hanger was that the tubing hanger could be landed directly into the wellhead. This eliminated the tubing spool. Hydraulically pressurized sliding sleeves were also used to open and close ports into the tubing annulus for annulus access. However, access to the production tubing annulus remained an problem.

A dual bore, eccentric tubing hanger was developed to resolve the need for a reliable access to the production tubing annulus below the tubing hanger, to provide an adequate flow area through the tubing hanger and to provide a reasonably reliable flow control device. The dual bore, eccentric tubing hanger included a vertically disposed annulus access bore through the body of the tubing hanger. The vertical bore permitted the setting of a wireline deployed plug, similar to the one used for the production bore itself, in annulus access bore to close the annulus access bore in the tubing hanger. This eliminated the need for valves in the ports. However, because of the size of the annulus access bore, the production bore had to be moved off center and was therefore eccentrically disposed within the wellhead, i.e. no longer concentric. The dual bore, eccentric hanger also had to be oriented within the wellhead. Further, subsequent equipment also had to be oriented with respect to the dual bores in the tubing hanger.

With operations occurring from a floating vessel, particularly a dynamically positioned vessel, it was necessary to have an emergency disconnect so that all flow to the surface could be closed, such as through the production bore and annulus access bore, and the riser disconnected in case the vessel floated off the well. The emergency disconnect also included the ability to cut off any wireline or tubing extending through the tubing hanger bores in the well. Certain prior art wellhead systems do not have adequate emergency disconnects should the vessel float off site.

Because the dual bore, eccentric tubing hanger required that a plug be set in either or both the production bore and/or annulus access bore in the tubing hanger, the dual bore x'mas tree and dual bore riser were developed. Thus, the dual bore, eccentric tubing hanger caused the development of a suite of tools and equipment commonly called the dual bore completion riser system. This system has grown in complexity and scale over the years to such a extent that from economic and logistic points of view, thc efforts of field developers have become economically

handicapped. Further, and more importantly, the dual bore completion has limited the size of the production bore through a particular sized tubing hanger and wellhead system.

To overcome the deficiencies of the dual bore completion system, a horizontal spool tree system, called the SpoolTree completion system, was developed and commercialized by Cooper Cameron. See U.S. Patent 5,544,707. The horizontal spool tree system does not use a vertical annulus access bore through the body of the tubing hanger to access the production tubing annulus and instead provides a spool tree with a lateral production passageway and a flow passageway around the tubing hanger and production passageway utilizing hydraulically operated gate valves for flow control. The flow passageway around the tubing hanger in the spool tree has many advantages, one principal advantage being its simplicity.

The concentric completion, the dual bore completion, and the horizontal completion for deepwater subsea wells, each has its disadvantages. In the concentric completion, the annulus access valves, particularly the poppets and spool valves, tended to be unreliable and caused this style of completion to become outmoded and even unsafe. Further the space required by the hanger-loaded valves in the hanger body severely limited the production bore size for a given size wellhead.

In the dual bore completion, the expense and logistics of the dual bore completion riser system were a disadvantage. Further, the space required by the dual eccentric bores in the hanger body even more severely limited the production bore size for a given wellhead. This holds true of the dual bore completion riser system. The size of the riser and the tubing hanger running tool is limited by the size of the subsea blowout preventer stack, typically having an 18-3/4 inch bore.

In a dual bore completion, if a 2 inch annulus access bore is placed beside a 9 inch production bore, the tubing hanger and production tubing will not pass through a 9-5/8 inch casing

in a conventional wellhead system. A 10-3/4 inch casing or 11-3/4 inch casing is required. A monobore completion is an alternative to the dual bore completion. However, one disadvantage of a monobore riser is that it is necessary to have the capability of setting a plug in either the production bore or the annulus access bore. This requires that the monobore system have a bore selector to allow the setting of a plug in either the production bore or annulus access bore.

An advantage of a concentric production bore is that the tree cap for the tree does not have to be oriented. In a dual bore completion there are two bores, one for production and one for annulus access, thus requiring that the tree cap be oriented. Further, it is necessary to land a seal in both bores.

The horizontal tree encounters design difficulties, particularly for large bore concentric completions for bores which are 9 inches or greater. A horizontal tree requires a 9 inch test tree package for a 9 inch bore. Presently a 9 inch test tree package is not available for a subsea well, although there are 9 inch land based trees for wells and thus, there are 9 inch x'mas trees. This is currently the limitation in the market of available tools. The lack of cutting valves in the vertical run during well test requires the use of BOP test trees when installing the horizontal tree hangers to complete the well. These were developed to allow vertical access up to (currently) 7 inch completions. Typically, the production bore for a horizontal tree is 5 inches or possibly as large as 7 inches. Some in the industry are still concerned with thc reliability of the plugs in thc vertical run of the tubing hanger and prefer a more conventional design, but for the disadvantages of the dual bore design used in their application.

In the prior art designs, there must be a connector and the tree must be oriented to and locked to that connector. This requires the reestablishment of communication from below the tubing hanger to the connector. Often these wells are at a depth which will not allow a diver to

make the connection. Thus, there needs to be a practical connection for both fluid paths, i.e. production bore and annulus access bore, to allow circulation below the tubing hanger.

The present invention overcomes the deficiencies of the prior art.

The present invention is a wellhead system having a tubing spool adapted for mounting on a subsea wellhead and a tree assembly connected to the top of the tubing spool. The tubing spool and tree assembly include a concentric flowbore extending therethrough for production. A tubing hanger is disposed within the tubing spool for suspending production tubing into the wellbore, the production tubing being concentrically disposed within the wellhead system and wellbore.

The tubing spool includes an annulus circulation flow path extending from the annulus around the production tubing below the seals sealing the tubing hanger within the tubing spool to an annular area above the tubing hanger seals so as to provide an annulus circulation flow path extending around the tubing hanger. The annulus circulation flow path includes at least one annulus master valve which may, along with the annulus circulation flow path, be disposed within the wall of the tubing spool.

Another annulus circulation flow path is disposed in the tree block of the tree assembly with the annulus circulation flow path communicating with the annular area in the upper end of the tubing spool and extending around the production master valve and production swab valve in the production flowbore of the tree block, to the upper terminal end of the tree block. A cross-over flow passageway communicates with the annulus circulation flow path in the tree block with an annulus master valve, an annulus swab valve, and a cross-over valve controlling flow through the annulus circulation flow path and the cross-over flow passageway.

The wellhead assembly forms two principal circulation paths, an annulus circulation path and a production circulation path. The production circulation path extends through the production tubing flowbore, the tubing hanger flowbore, the tree block flowbore and through the production master valve to a flow line. The annulus circulation path extends from the production tubing annulus, through the annulus circulation flow path around the tubing hanger and through the annulus circulation flow path around the production master valve and production swab valve in the tree block. The production circulation path extends to the surface through a riser and the annulus circulation path extends to the surface through a conduit, preferably exterior to the riser. The conduit is preferably a spoolable hose.

The wellhead system of the present invention provides multiple circulation paths. One principal circulation path is through the production circulation path, through an aperture downhole in the lower end of the production tubing communicating with the production tubing annulus, and through the annulus circulation path to the surface through the conduit. Circulation may be provided for other purposes including gas lift, removal of fluids in the riser, removal of captured gas in the annulus, circulation due to loss of a pressure barrier, or circulation due to the failure of the tubing hanger, among others.

The present invention provides many advantages over the prior art as are more fully described in the description of the preferred embodiments. One particular advantage of the present invention is it's use for a large bore completion. Another principal advantage of the present invention is the provision of a concentric flowbore through the wellhead system thereby simplifying the apparatus and methods for the installation and use of the wellhead system. Further, the present invention permits the use of a more conventional tree assembly with standard valves. Another principal advantage of the present invention is the benefit of providing annulus access circulation

paths which are completely housed within the wall of the tubing spool and/or tree assembly. A still another advantage of the present invention is its ability to use a monobore riser without a bore selector. The present invention also permits the use of a fast emergency disconnect.

Other objects and advantages of the present invention will be apparent from the following description of the preferred embodiments.

For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

Figure 1 is a cross-sectional view in elevation of one embodiment of the wellhead system of the present invention;

Figure 2 is a cross-sectional view in elevation of another embodiment of the wellhead system of the present invention;

Figure 3 is a schematic of the hydraulic circuit of the embodiments of Figures 1 and 2; and

Figure 4 is a cross-sectional view in elevation of another embodiment of the wellhead system of the present invention used in a horizontal tree.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

The present invention relates to methods and apparatus for a subsea wellhead assembly.

The present invention is susceptible to embodiments of different forms. In particular, various embodiments of the present invention provide a number of different constructions and methods of operation of the system. The embodiments of the present invention also provide a plurality of methods for using the wellhead assembly of the present invention. It is to be fully recognized that the different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce desired results. Reference to up or down will be made for purposes of description with up meaning toward the surface and down meaning toward the mudline.

Referring initially to Figure 1, there is shown a preferred embodiment of the present invention. The wellhead system 10 is shown disposed on wellhead 12. A tubing spool 20 is connected to wellhead 12 by means of a spool connector 14. A sleeve 16 extends from the tubing spool body 22 down into the wellhead 12 and seals with the innermost casing hanger 18 supported within the wellhead 12. Sleeve 16 also provides an orientation surface 24 for orienting tubing hanger 30. Tubing hanger 30 is housed in tubing spool flowbore 56 and is landed on support shoulder 29 on tubing spool body 22 to suspend production tubing 26 into the wellbore 28. Seal assembly 31 seals between tubing hanger 30 and tubing spool body 22. Tubing hanger 30 has a flowbore 33 in fluid communication with the flowbore 27 of production tubing 26. Tubing hanger 30 also includes a profile 35 for receiving a closure member such as a wireline plug (not shown). Production tubing annulus 32 is formed between production tubing 26 and the innermost casing string (not shown) on casing hanger 18. It can be seen that an annular flowpath 34 extends through the bore 36 of sleeve 16 below tubing hanger 30.

A first annulus passageway 40 extends from an internal opening 42 in a generally vertical portion of wall 38 of tubing spool body 22 below seal assembly 31 and preferably below support

shoulder 37 and through the wall 38 to an external opening 44 in the wall 38. A second annulus passageway 50 extends from an internal opening 52 in a generally vertical portion of wall 38 above seal assembly 31 and through wall 38 to an external opening 54 in wall 38. An annulus master valve 46 is disposed on the exterior of tubing spool body 22 and includes a flow passageway 48 extending between external openings 44, 54. Annulus master valve 46 controls fluid flow through flow passageway 48. First and second annulus passageways 40, 50, together with valve flow passageway 48, form an annulus circulation flowpath 60 around tubing hanger 30. Flowpath 60 is external to the flowbore 56 through tubing spool body 22.

A tree assembly 70 is disposed on tubing spool 20. Tree assembly 70 includes a tree block 72 having a tree connector 74 mounted on its lower end for connecting tree assembly 70 to the upper end of tubing spool 20. A gasket seal 76 is disposed between the tree block 72 and tubing spool body 22 to seal the connection and a lock 78 is provided to lock the connection. The gasket 76, tree connector 74 and lock 78 are conventional and well known in the art. A sleeve or tube 80 extends from counterbore 81 in the tree block 72 down into the top of the tubing spool flowbore 56 in body 22. Seals 82, 84 seal the sleeve 80 with tree block 72 and tubing spool body 22 above and below the connection between the tubing spool body 22 and tree block 72. A test port 86 extends through tree block 72 for testing gasket seal 76 so that metal gasket seal 76 may be tested from the inside of counterbore 81 between seals 82, 84. Leakage around sleeve 80 may also be monitored through test port 86.

Tree block 72 includes a wall 75 forming a vertical concentric production flowbore 88 extending therethrough and a horizontal crossover flow passageway 90 extending laterally through wall 75 and preferably intersecting concentric flowbore 88. It should be appreciated that cross-over flow passageway 90 may communicate with the flowbore 88 exteriorly of the tree block 22. A

crossover valve 96 is attached to the exterior of tree block 72 at the other end 98 of crossover passageway 90. A lateral production bore 91 also extends through wall 75 from the exterior of tree body 72 to concentric flowbore 88. A production wing valve 94 is attached to the exterior of tree block 72 at one end 93 of lateral production bore 91. A production master valve 100 is disposed in concentric flowbore 88 below the junction 97 with lateral production bore 91 and a production swab valve 102 is disposed in concentric production flowbore 88 above the junction at 97 of lateral production bore 91 and flowbore 88. A flowline 162 is connected to production wing valve 94 for communication with lateral production bore 91.

A production mandrel 110 projects into counterbore 92 in the lower end of concentric production flowbore 88 and is sealed with tree block 72 at 112. Production mandrel 110 extends downwardly into a counterbore 114 in tubing hanger 30 and is sealed at 116. Production mandrel 110 has a flowbore 118 communicating with flowbore 88 of tree block 72 and with flowbore 33 of tubing hanger 30. Production mandrel 110 forms an annular passageway 120 with sleeve 80 and flowbore 56 of tubing spool body 22.

Tree block 72 further includes a first annulus passageway 122 having a vertical portion extending from an internal opening 124 in a horizontal portion of the wall 75 of tree block 72 formed by counterbore 81 and a lateral portion extending through the wall 75 to an external opening 126 in the wall 75. A second annulus passageway 128 has a vertical portion extending from an upper external opening 130 in wall 75 at the upper terminal end 132 of tree block 72 and a lateral portion extending through wall 75 to an external opening 134 in wall 75.

An external flow passageway 136 extending between external openings 126, 134 is disposed on the exterior of tubing spool body 22 and communicates by passageway 138 with crossover flow passageway 90. An annulus master valve 140 is disposed in external flow

passageway 136 below the junction at 137 with crossover passageway 90 and an annulus swab valve 142 is disposed in passageway 136 above the junction at 137. The annulus master valve 140 and annulus swab valve 142 control fluid flow through flow passageway 136 and through crossover passageway 90, together with crossover valve 96. First and second annulus passageways 122, 128, together with external flow passageway 136, form an annulus circulation flowpath 144 adjacent to concentric production flowbore 88. Flowpath 136 is external to flowbore 88 through tree block 72. Thus, annulus access via annulus circulation flowpath 144 comes back into tree block 72, such that when a riser package is connected to the top of tree assembly 70, annulus access is available between the riser package and production tubing annulus 32.

In the embodiment of Figure 1, the production bore 88 is concentric and the second annulus passageway 128 for annulus access is off center. Thus to connect to tree block 72, two stabs are required, one for the production bore 120 and one for second annulus passageway 128 for annulus access.

A stab mandrel 150 is mounted on the upper end 132 of tree block 72 for connection to a connector 152. Stab mandrel 150 includes an inner counterbore 145 receiving the lower end of an inner sleeve 154 extending downwardly from connector 152, a medial counterbore 146 communicating with second annulus passageway 128, and an outer counterbore 148 receiving the lower end of an outer pack-off sleeve 156 extending downwardly from connector 152. Seals 155, 157 are provided around each end of the sleeves 154, 156, respectively, to seal their connection with mandrel 150 and connector 152. Sleeves 154, 156 form an annular flow passageway 255 therebetween communicating with second annulus passageway 128. Connector 152 includes a production flowbore 158 communicating with concentric production flowbore 88 in tree block 72 and an annulus flowbore 160 communicating with annular flow passageway 255 and thus with

second annulus passageway 128. A test port 163 may also be provided in connector 152 to test the seals 157 and monitor for pressure leaks around outer pack-off sleeve 156.

The connector 152 may connect the tree assembly 70 to various equipment such as a blowout preventer stack (not shown). This allows the tree assembly 70 to be tied back to the surface, using the running tool that was used to lower tubing hanger 30, by plugging the running tool into the upper end of production flowbore 88 near the top of the tree block 72. The inside of the flowbore 88 would be packed off and the pipe rams would be closed around the work string (not shown) on the running tool. A high pressure internal cap may be lowered through the BOP stack and installed inside the production bore 88 for capping off in the tree block 72 of tree assembly 70. If the connector 152 is an 18-3/4 inch connector, then an 18-3/4 inch workover running package could also be used for connected to tree assembly 70.

The wellhead assembly 10 forms two principal circulation paths, an annulus circulation path A and a production circulation path P. The production circulation path P extends through the production tubing flowbore 27, through the tubing hanger flowbore 33, through production mandrel flowbore 118, through concentric production flowbore 88, and through the flowbore 158 of connector 152 or through the flowbore of a running tool and work string extending to the surface. The annulus circulation path A extends through the production tubing annulus 32, through annular flow path 34 in sleeve 16, through annulus circulation flowpath 60, through annular passageway 120 around production mandrel 110, through annulus circulation flowpath 144, through annulus flowbore 160 in connector 152 and through choke and kill lines (not shown) connected to the blowout preventer (not shown) to the surface. Thus, there is automatic access to the production tubing annulus 32 from the top 132 of the tree assembly 70.

It should be appreciated that the annulus circulation path A and production circulation path P may communicate downhole by any of various means, such as for example a sliding sleeve, well known in the art. Thus a surface-to-downhole circulation path is formed by production circulation path P and annulus circulation path A and the circulation capability of the wellhead assembly 10 has been maintained using the more conventional concentric production bore tree assembly 70.

During production, production swab valve 102 and crossover valve 96 are closed and production fluids flow up through that portion of the production circulation path P below valve 102 and through the production master valves 100 and production wing valve 94 to the flowline 162.

Referring now to Figure 2, there is shown another embodiment of the wellhead system 170 of the present invention. For convenience, the same reference numerals will be used for elements in the embodiment of Figure 2 which are substantially the same as the elements of the embodiment of Figure 1. The wellhead system 170 of Figure 2 varies from wellhead system 10 in that annulus circulation paths A and P are internal to the tubing spool 180 and the tree assembly 190 of wellhead system 170.

The tubing spool 180 includes an enlarged portion or hip 172 in which is housed annulus master valve 174 and workover valve 176. The first annulus passageway 178 extends from internal opening 42 in the wall 38 of tubing spool body 22, through annulus master valve 174 and intersects the second annulus passageway 180 extending through workover valve 176 from internal opening 52 in wall 38. First and second annulus passageways 178, 180 form an annulus circulation flowpath 182 around tubing hanger 30 which is external to the flowbore 56 through tubing spool body 22. Thus annulus circulation flowpath 182, annulus master valve 174, and workover valve 176 are completely housed within tubing spool body 22.

The tree assembly 190 includes a tree block 191 with an enlarged portion or hip 192 in which is housed crossover valve 194, annulus master valve 196 and annulus swab valve 198. The first annulus passageway 200 extends from internal opening 124 in the wall 75 of tree block 191 and through annulus master valve 196 to the junction 195 with the second annulus passageway 202 extending through annulus swab valve 198 to external opening 204 in the bottom of an outer counterbore 234 in the upper end 208 of tree block 191. The first and second annulus passageways 200, 202 communicate with crossover passageway 90 at junction 195. The annulus master valve 196 and annulus swab valve 198 control fluid flow through flow passageways 200, 202 and through crossover passageway 90, together with crossover valve 194. First and second annulus passageways 200, 202 form an annulus circulation flowpath 210 adjacent to concentric production flowbore 88. Flowpath 210 is external to the flowbore 88 and annulus circulation flowpath 210, crossover valve 194, and annulus master valves 196, 198 are completely housed within tree block 191. It should be appreciated that there may be other valves, such as flow isolation valves (not shown).

Referring now to Figures 2 and 3, the wellhead assembly 170 forms two principal circulation paths, annulus circulation path A and production circulation path P. The production circulation path P is the same as that described with respect to the embodiment of Figure 1. Annulus circulation path A of wellhead assembly 170 extends through the production tubing annulus 32, through annular flow path 34 in sleeve 16, through annulus circulation flowpath 182, through annular passageway 120 around production mandrel 110, and through annulus circulation flowpath 210 to the terminal end 208 of tree assembly 190.

As an alternative to installing a blowout preventer stack, as described with respect to the embodiment of Figure 1, a monobore completion package 220 is shown installed on top of tree

assembly 190. The monobore completion package 220 requires only one flowbore 222, as distinguished from a dual bore completion, since production flowbores 33, 118 in tubing spool 180 and production flowbore 88 in tree block 191 provide a single concentric flowbore bore in wellhead system 170 through which tools may be run into wellbore 28. Annulus circulation path A is only used for circulation using the previously described control valves. Thus, there is no wireline or tubing extending through annulus circulation path A that must be sheared in case of an emergency disconnect. This greatly simplifies the running package for the riser (not shown) connected to the monobore completion package 220.

Referring again to Figure 2, the tubing hanger 30 has already been landed and the BOP stack removed. The monobore completion package 220 is now connected to the tree assembly 190 for production. The monobore completion package 220 includes a riser mandrel 224 connected to a stress joint 226 by an emergency disconnect 228 with the stress joint 226 being connected to the riser (not shown) extending to the surface. It should be appreciated that the completion package will also include a running tool and work string.

The riser mandrel 224 is mounted on the upper end 208 of tree block 191 by mating flanges 225 or to a connector (not shown). Tree block 191 includes an inner counterbore 230 receiving the lower end of an inner sleeve 232 extending downwardly from riser mandrel 224 and the outer counterbore 234 receiving the lower end of an outer pack-off sleeve 236 extending downwardly from riser mandrel 224. Seals 233, 235 are provided around each end of the sleeves 232, 236, respectively, to seal their connection with riser mandrel 224 and tree block 191. Flowbore 222 of riser mandrel 224 includes first and second flow control valves 238, 240 for controlling flow through riser mandrel 224.

Inner and outer sleeves 232, 236 form an annular flow passgeway 242 which communicates with second annular passageway 202 at the bottom of counterbore 234 as part of annulus flow passageway 244, and which extends through the wall of riser mandrel 224 to an external connection 246 on the side of riser mandrel 224. A flow control valve 252 is disposed in flow passageway 244 to control flow therethrough.

An annulus access conduit 250 is connected to riser mandrel 224 at connection 246 and extends to the surface. Conduit 250 may be a spoolable flexible hose. The hose 250 is attached at the surface and then is unspooled as the monobore completion package 220 is lowered on the riser (not shown) through open water to tree assembly 190. The hose 250 is distinguished from a choke and kill line which is a hard pipe that is made up section by section with the riser. Hose 250 is external to the riser and is preferably a two inch hose. The riser and hose 250 extend to the surface for circulation through the annulus circulation path A and production circulation path P.

It should be appreciated that flow passageway 244 may communicate with the surface by an alternate path to the surface other than conduit 250. The hose 250 may be a part of the completion running package or of an intervention running package. It should be appreciated that the annulus flow can be incorporated through a workover umbilical since no tools are run through annulus circulation path A. All that is required is fluid circulation.

There may be occasions when the monobore riser may be connected to the tree assembly 190 without a conduit 250. Conduit 250 is not required if there is no contemplation to circulate the production annulus 32. If the production packer is sealing and if the production tubing 26 is in good condition, it may be unnecessary to have circulation capability. However, conduit 250 is preferred since, over time, the capability for circulation may become necessary. It should be appreciated that conduit 250 may be connected later to provide a circulation path.

The internal annulus circulation flowpaths 182, 210 and valves 174, 176, 194, 196, 198 provide many advantages over external piping and valves. Monoblocks, such as tubing spool 180 and tree block 191, provide greater safety and reliability and require fewer connections that have to be relied upon.

It is preferred to have the annulus circulation flowpaths 182, 210 and valves 174, 176, 194, 196, 198 internal of the tubing spool 180 and tree block 191. By having internal annulus circulation passageways 182, 210 close to production flowpath P, the fluids in annulus circulation passageways 182, 210 retain the heat from the production fluids passing through production circulation path P thereby preventing the formation of hydrates. This is particularly advantageous in deeper waters where hydrate formation becomes a problem.

Neither wellhead system 10 or 170 require the setting of wireline plugs in second annulus passageways 128 or 202 to close annulus circulation path A. By disposing the annulus circulaation passageways 182, 210 at an angle instead of vertically, tubing spools 20, 180 and tree blocks 72, 191 may be smaller in size. The present invention may allow the reduction in the height of the tree. Having first and second annulus passageway 200, 202 at an angle is particularly advantageous in wellhead system 170. This allows sufficient room to locate cross-over valve 194 internally of tree block 191 and allows passageways 200, 202 forming annulus circulation passageway 210 to extend around internal cross-over valve 194.

Also since there need be no stab into second annulus passageways 128 or 202, the tree cap (not shown) may be non-orienting which simplifies the tree cap design. The running package for systems 10, 170 only uses a stab 154, 232 and a sleeve 148, 206, respectively, for connecting to the top of the tree block 72, 191 to form the annular area 155, 242 for communication with the tubing annulus 32.

Pressure in the production tubing annulus 32 is continuously monitored. Packer leakage is also monitored. As the well heats up, annulus pressure can rise. If a pressure build up is detected, production is shut in by closing the production master valve 100. The cross-over valve 96, as well as valves 140 and 46 downstream to the annulus 32, are then opened. This allows the built-up annulus pressure to vent out through flow line 162.

In operation, the tubing spool 20, 180 is connected to the wellhead 12 by tubing spool connector 14. The tubing hanger 30 and production tubing 26 are lowered and installed within tubing spool 20, 180. The tree assembly 70, 190 is subsequently lowered on a running tool, as part of a completion package, on a riser extending from the surface. Annulus flowpath A and production flowpath P are thus formed. A blowout preventer stack is then connected by connector 152 to the top of the tree assembly 70, 190. The well is completed and monobore completion package 220 is lowered and connected to tree assembly 70, 190.

For circulation between the annulus flowpath A and production flowpath P, a cross-over aperture is provided downhole between the flowbore 27 of the production tubing 26 and the production tubing annulus 32. This may be accomplished by several means. In one example, a sliding sleeve may be placed downhole adjacent the end of production tubing 26 above the production packer (not shown). The sliding sleeve is opened to gain access between the flowbore 27 and annulus 32. In another example, circulation may occur around the lower terminal end of the production tubing 26 and into the annulus 32 before the production packer is set. This allows the tubing hanger 30 to be landed, circulation to remove the heavy fluid, and then the production packer to be set. In still another scenario, if the production packer is leaking, then there can be circulation around the lower end of the production tubing or if the production tubing has parted, then there can be circulation through the parting of the tubing. In an emergency situation, a

perforating gun can be lowered downhole and the production tubing 26 perforated to gain access to the annulus 32. It should be appreciated that other means for fluid communication may be provided downhole between the flow bore 27 of the production tubing 26 and the annulus 32 around the tubing 26 to allow fluid circulation between production circulation path P and annulus circulation path A.

Circulation through the annulus may be desirable for various reasons such as for gas lift. Gas is first pumped down the work string with the valve configuration such that there is flow through the cross-over valve 194 forcing the sea water out of the work string and into the flow line 162 rather than downhole into the well. Once the sea water has been removed, the cross-over valve 194 is closed allowing the gas from the surface to be pumped down annulus circulation path A to help lift the hydrocarbons up the production passageway P to the surface.

Circulation may be required for other reasons such as to circulate out gas captured in annulus 32. Another reason for circulation is the loss of a pressure barrier, such as a leak or parting in the production tubing 26 or a failure of the production packer. Another possibility is a failure of the tubing hanger 30, such as due to a leak in the tubing hanger seals 76.

After the well has been completed and hydrocarbons flowed to the surface through the production flowpath P and the riser, it may be necessary to conduct an intervention or workover. In a workover, the well is shut in and the production master valve 100 and the annulus master valve 140, 196 are closed. Fluids are then circulated down the riser, through the crossover valve 96, 194, and up the conduit 250 to circulate out all of the hydrocarbons inside the riser. Dumping hydrocarbons into the sea is prohibited due to the environmental problem.

Once the hydrocarbons have been removed from the riser, to gain access to the well safely, the flow bore P and annulus A are circulated replacing the well fluids with a heavy mud to control

the well. The annulus A and flowbore P are loaded up with heavy mud to kill the well and make it safe. There is also the alternative to dead head the well without flowing mud down the well and pressuring and forcing fluid back into the production zone. This is typically not desired because it adversely impacts the reservoir. With the well killed, the monobore completion package 220 is disconnected from the tree assembly 70, 190 and then the tree assembly 70, 190 may be removed to obtain access to the tubing hanger 30 for its removal and workover. An intervention or workover running package is then lowered and connected to tubing spool 20, 180.

The embodiments of the present invention provide many advantages over the prior art and are particularly advantageous for a large bore completion. A large bore completion is defined as a completion with a 3 inch or larger production bore, and more particularly to a 3 inch or larger production bore which is concentrically disposed in the wellhead system, and still more particularly a 3 inch or larger production bore concentrically disposed in a 7 inch casing string. Preferably the large bore completion is a completion with a 9 inch or larger production bore, and more particularly to a 9 inch or larger production bore which is concentrically disposed in the wellhead system, and still more particularly a 9 inch production bore concentrically disposed in a 9-5/8 inch casing string. This allows a maximum sized completion in a minimum sized wellhead. The centering of the production bore and the elimination of a vertical annulus port through the tubing hanger allows the maximization of the production bore for any given wellhead. The present invention resolves the long felt need in the industry for a simplified large bore subsea completion system, without the need to develop a large bore, BOP test tree.

The present invention also provides a concentric flowbore through the wellhead system. This concentricity permits the use of a concentric bore tubing hanger which simplifies the tubing hanger running tool since it only has to have one bore through it and the installation of the tubing

hanger since the tubing spool can be used to orient the tubing hanger. Further, a subsea test tree can also be used to run the concentric tubing hanger which allows better control of the tubing hanger as it is run into the well. There are also safety and reservoir benefits. By using a concentric tree assembly, the present invention provides the wellhead design features preferred by the industry, such as accessibility to the well from the standpoint of fluid flow.

The use of a concentric tubing hanger permits the use of a conventional test tree such that the well can be unloaded after running the production tubing. After the well has been perforated, the formation begins taking completion fluid which is typically not good for the reservoir. The objective is to land the tubing hanger and remove the completion fluid as quickly as possible by flowing the completion fluids out of the production tubing to minimize reservoir damage, then open up the valves to produce. In terms of production timing and installation, the present invention facilitates the unloading of the well.

Concentricity also simplifies the large bore completion. The riser package is concentric so as not to require orientation with the tree assembly and yet provides all the necessary circulation. Although orientation between the x'mas tree and tubing spool is not required for the present invention, it may still be required for other fluid couplings. The downhole control lines may pass through the tubing hanger thus requiring stabs in the tree block to be oriented with the tubing hanger whereby ports in the tubing hanger will receive stabs from the tree block. This is conventional. As an alternative, the control lines may extend horizontally through the tubing spool so as not to pass them through the tubing hanger. One advantage of horizontal connections is that as soon as the tubing hanger is landed, the other connections can be tested to be sure that everything is operating. If the ports extend through the tubing hanger, this cannot be determined until after the BOP stack and riser have been removed and the tree installed. The disadvantage of

the horizontal connections is that additional coupler plates have to be mounted on the tubing spool in addition to other logistical problems.

The present invention allows the use of a more conventional tree assembly with a standard set of valves in the tree assembly so as not to require the use of plugs. The annulus valves can be internal or exterior to the tree block. The cross-over valve can be interior since the annulus access passageways need not be vertical to receive tools. The benefits of this new reconfiguration allow the design of the "vertical tree" to revert to the simpler single bore, concentric design, which simplifies the required tools and replaces the problematic in-the-hanger annulus access valves with actuated gate valves which are heavily favored by the industry. One advantage of this configuration is the simplified hardware required for the actual implementation of the design.

The present invention allows the use of a standard tree assembly with many of the benefits of the horizontal tree. The present invention provides annulus flow around the tubing hanger and a cross-over to kill the well with access through the top of the tree assembly. Annulus circulation flowpaths 60, 182 provide a bypass around tubing hanger 30 while still using a concentric tree assembly.

The present invention also provides many advantages with respect to the connections in the wellhead system. There need be no external connection between the tubing spool 20, 180 and the tree block 72, 191 nor between the tree block 72, 191 and the riser package. By bringing all of the annulus connections back into the wellhead system, no external flow line connections are required. In the prior art, once the tubing hanger is landed, there is no means for communicating with the annulus unless the blowout preventer stack is modified for attachment to an outboard annulus flow line or an ROV connection is provided.

The present invention also provides a simplified method of connecting a concentric production bore to the top of the tree assembly and still provide two flow paths to the surface for circulation. The present invention utilizes a simple monobore riser. A dual bore riser is not required and neither is a bore selector for use with the monobore riser. Conduit 250 provides the necessary circulation flow path to the surface.

The present invention eliminates the need for a high pressure workover package for annulus access. It is only necessary to pass well tools through the concentric production bore. The bore selector is eliminated and a line of cutting valves is eliminated. All that is required is an isolation valve for the hose.

The present invention is also advantageous for fast emergency disconnects. While using a dynamically positioned rig, control may be lost when the rig floats off its position over the well. The present invention allows the well to be shut in, isolated, and separated from the dynamically positioned rig in a matter of seconds, thus assuring control of the well.

Referring now to Figure 4, there is shown still another embodiment of the present invention. The wellhead system 260 of Figure 4 varies from wellhead systems 10, 170 in that the tubing spool 270 is a horizontal tree with a lateral production bore 212. The wellhead system 260 is disposed on a wellhead 262 having a bore 264 in which is disposed one or more casing hangers suspending casing within the wellbore, including innermost casing hanger 266 supporting casing 268. Horizontal tree 270 is mounted on the top of wellhead 262 by a connector 274. Horizontal tree 270 includes a bore 276 which includes a tubing hanger orientation helix 278.

A tubing hanger 280 is received within bore 264 of horizontal tree 270 and is oriented by orientation helix 278 such that a lateral flow port 282 in tubing hanger 280 is in alignment with lateral flowbore 272 in horizontal tree 270. Seals 286, 287 are provided around tubing hanger 280

to sealingly engage horizontal tree 270 thereby sealing lateral production flowbores 272, 282. Tubing hanger 280 supports production tubing 284 within casing 268 thereby forming a production tubing annulus 288. Production tubing 284 also forms an annular area 290 with wellhead bore 264 and horizontal tree bore 292. It should be appreciated that a second tubing hanger may be disposed in the wellhead system 260 such as shown in U.S. Patent 5,372,199, hereby incorporated herein by reference.

A first annulus passageway 294 extends through wall 295 from annulus 290 to an inner annulus master valve 296. A valve flow passageway 298 extends from inner annulus master valve 296 through a workover valve 300 to a second annulus passageway 302. Second annulus passageway 302 extends back through the wall 295 of horizontal tree 270 to an area 304 above seals 287 of tubing hanger 280. Still another annulus line 306 communicates with valve flow passageway 298 and includes an outer annulus valve 308 for controlling flow therethrough. A cross-over line 310 also communicates with valve flow passageway 298 and with production line 312 in flow communication with lateral flowbores 272, 282. A cross-over valve 314 controls flow through cross-over line 310 and inner production master valve 316 controls flow through lateral production flowbores 272, 282. An outer production master valve 318 in fluid communication with production line 312 controls flow through a flow line 320. Although valve flow passageway 298 and cross-over passageway 310 are shown extending externally of horizontal tree 270, it should be appreciated that either or both valve flow passageway 298 and cross-over passageway 310 may be disposed in the wall of horizontal tree 270 as described with respect to the wellhead systems 10, 170 of Figures 1 and 2.

A modified conventional x'mas tree 330 is mounted on horizontal tree 270. A plug or isolation sleeve 356 extends from tree 330 into the bore 358 in tubing hanger 280, with seals 360

being provided to seal the connection. Upper tree 330 includes a first annulus passageway 332 extending from area 304 through the wall 335 of tree 330 to communicate with an external flow passageway 334 which extends and communicates with a second annulus passageway 336 that extends back through the wall 335 of tree 330 to communicate with a counterbore 338 in the upper end of tree 330. An annulus swab valve 340 is disposed in external flow passageway 334 to control flow therethrough. Upper tree 330 is connected to the upper end of horizontal tree 270 by a blowout preventer connector 322. The upper tree 330 includes a lower swab valve 342 and an upper swab valve 344 disposed in the flowbore 346 passing through tree 330 and communicating with the flowbore 350 of production tubing 284. A debris cover 352 is connected to the top of tree 330 by blowout preventer connector 354.

The embodiment of wellhead system 260 is directed to a larger bore than is presently available in a horizontal spool tree. Figure 4 shows a large bore completion and the use of smaller valves in upper tree 330, which is essentially a swab block. Annulus access is routed around tubing hanger 280 and around swab valves 342, 344, and therefore no outboard connectors are required. Wellhead system 260 is particularly advantageous for guideline-less completions.

While preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit or teaching of this invention. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims which follow, the scope of which shall include all equivalents of the subject matter of the claims.

CLAIMS

1. An assembly for a wellhead on a subsea well comprising:
a spool adapted for mounting on the wellhead;
a tree connected to said spool;
a concentric flowbore extending through said spool and free; and
an annulus access bore extending at least partially through said spool and tree.

2. The assembly of claim 1, further including a cross-over flowbore communicating with said concentric flowbore and including a cross-over valve disposed on said tree.

3. The assembly of claim 1 or claim 2, wherein that portion of said annulus access bore extending through said spool is completely disposed within a wall of said spool.

4. The assembly of any of claims 1 to 3, further including at least one valve communicating with said portion and disposed within said spool wall.

5. The assembly of claim 1 or claim 2, wherein that portion of said annulus access bore extending through said tree is completely disposed within a wall of said tree.

6. The assembly of claim 5 further including at least one valve communicating with said portion and disposed within said tree wall.

7. The assembly of any preceding claims, wherein said concentric flowbore has a large bore diameter.

8. The assembly of claim 7 wherein said concentric flowbore has a diameter of at least nine inches.

9. The assembly of any preceding claim, wherein said annulus access bore extends through the connection between said spool and said tree.

10. The assembly of any preceding claim, further including a connector on said tree having a connector bore, with said annulus access bore communicating said connector bore.

11. The assembly of claim 10, further including a tubing hanger supported by said spool and suspending production tubing into the well; said production tubing forming an annulus and said annulus access bore communicating the annulus with said connector bore.

12. The assembly of claim 10 or claim 11, further including a conduit communicating with said connector bore and extending to the surface.

13. The assembly of any of claims 10 to 12, further including a monobore riser connected to said tree by said connector, said riser being without a bore selector.

14. The assembly of any of claims 10 to 12, wherein said connector includes an emergency disconnect.

15. The assembly of claim 1, wherein said spool includes a bore receiving a tubing hanger with seals sealing said tubing hanger and spool and said annulus access bore extends from a first opening in said spool bore below said tubing hanger seals to a second opening in said spool bore above said tubing hanger seals.

16. The assembly of claim 15, further including a lateral production port extending from said concentric flowbore and through said tree to a valve mounted on said tree; said tree having valves sed in said concentric flowbore above and below said lateral production port.

17. The assembly of claim 15, further including a lateral production port extending from said concentric flowbore and through said tubing hanger and spool to a valve mounted on said spool.

18. An assembly according to claim 1, further comprising:

a tubing hanger supported by said spool and suspending production tubing into the well; and

a monobore riser and a conduit extending to the surface;

the concentric flowbore also extending through said monobore riser; and

the annulus access bore communicating with an annulus around said production tubing, extending to an upper end of said tree and communicating with said conduit extending to the surface.

19. The assembly of claim 18, wherein said concentric flowbore is a 3 inch diameter production concentrically disposed in at least a 7 inch casing string suspended into the well by the wellhead.

20. The assembly of claim 18, wherein said concentric flowbore is a 9 inch diameter production are concentrically disposed in at least a 9-5/8 inch casing string suspended into the well by the wellhead.

21. An assembly according to claim 1, substantially as described with reference to the accompanying drawings.

22. A method of circulating fluids in a subsea well comprising:

extending a flowbore concentrically through a tree, spool, and wellhead;

suspending production tubing in the wellbore from a tubing hanger supported by the spool;

extending a riser from the tree to the surface;

extending an annulus access bore through the spool and tree from an annulus around the production tubing to an upper end of the tree;

opening an aperture in the production tubing downhole in the wellbore with the aperture communicating the annulus with a flowbore of the production tubing; and

circulating fluid through said flowbore, opening and annulus access bore.

23. A method according to claim 22, substantially as described with reference to the accompanying drawings.

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Claims searched: All

Examiner: Philip Osman
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Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): E1F

Int Cl (Ed.7): E21B

Other: Online: WPI, EPODOC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X,P	GB2347161A	(FMC) Esp. Fig 5.	1, 22, at least
X,P	GB2342668A	(FMC) Esp. Fig 5	1, 22, at least
X	GB2335685A	(DRIL-QUIP) Esp. Page 3, Line 1 et seq.	1, 22, at least
X	GB2321658A	(ABB VETCO) Esp. Fig 1	1, 22, at least
X	GB2320513A	(ABB VETCO) Esp. Fig 1	1, 22, at least
X	GB2166775A	(BRITOIL) Esp. Fig 1.	1, 22, at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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